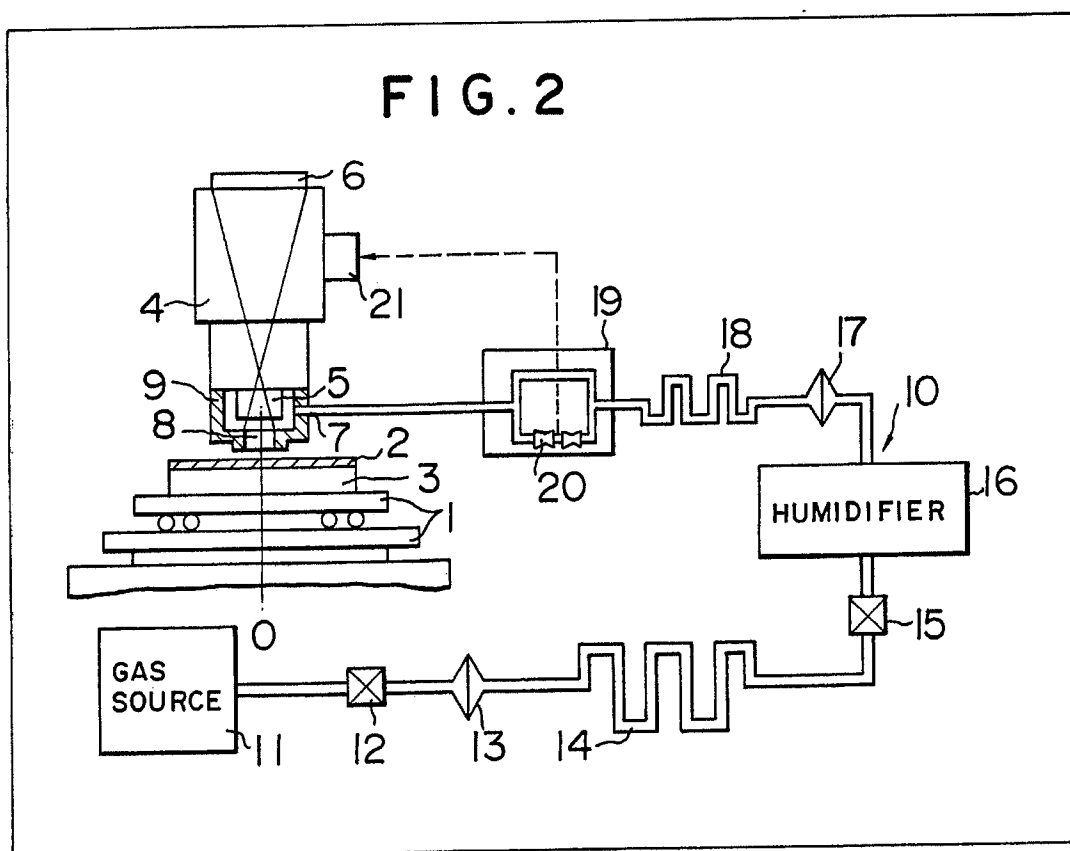


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(54) Controlled exposure

(57) The exposure, by projection or near contact printing, of a photoresist 2 which is sensitive to moisture, is carried out in the presence of gas of controlled humidity, eg. a relative humidity of 35%. The gas may be air or nitrogen (the latter being used for a negative-type photoresist). The gas may also be used in an air pressure-type focusing device for a step-and-repeat printer. The temperature of the gas is preferably controlled (Fig. 7). The controlled humidity exposure produces a uniform fine pattern.



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FIG. 1

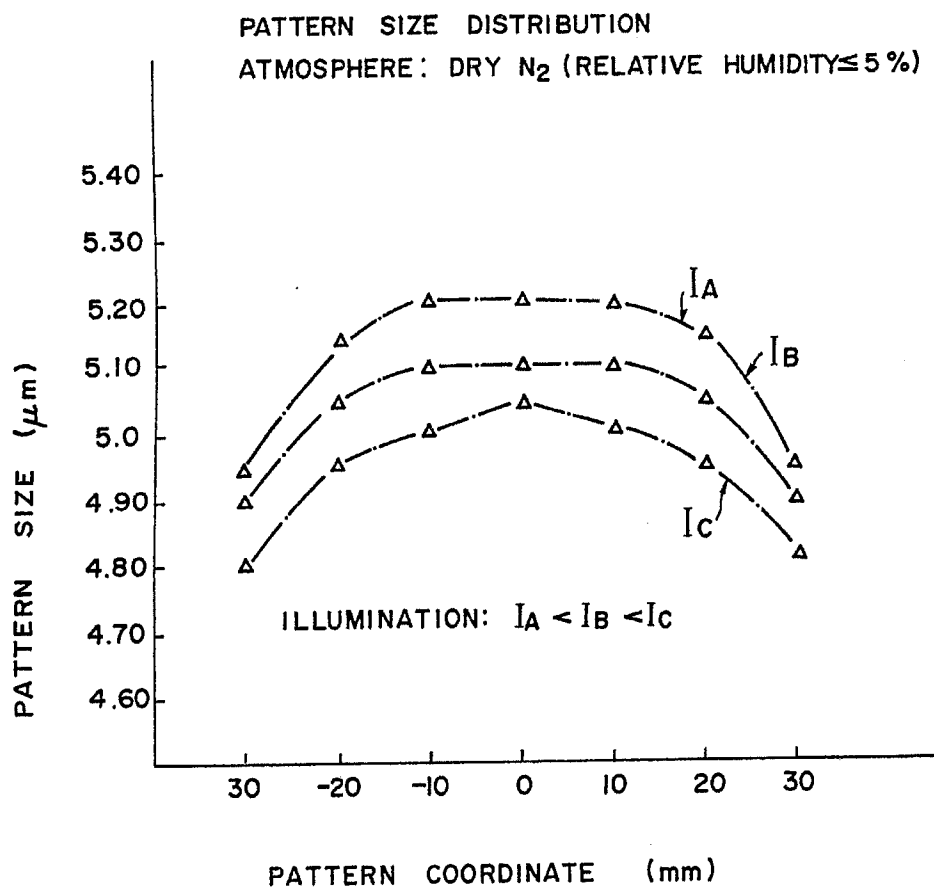


FIG. 2

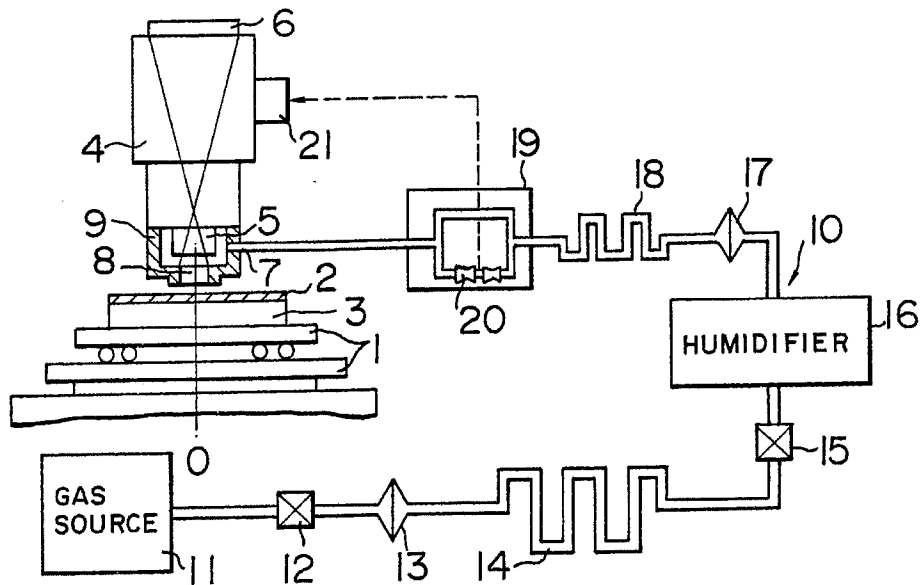


FIG. 3

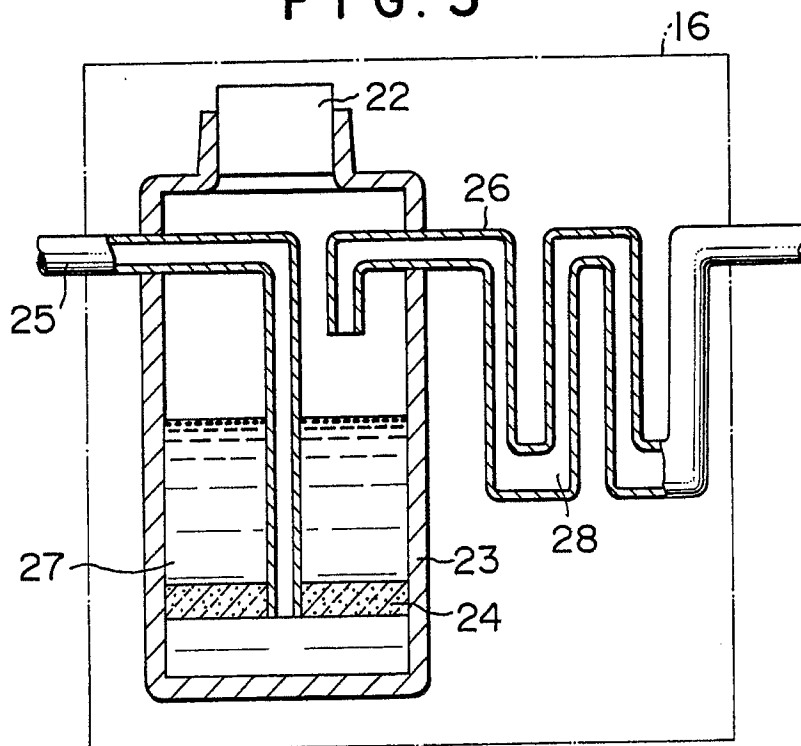


FIG. 4

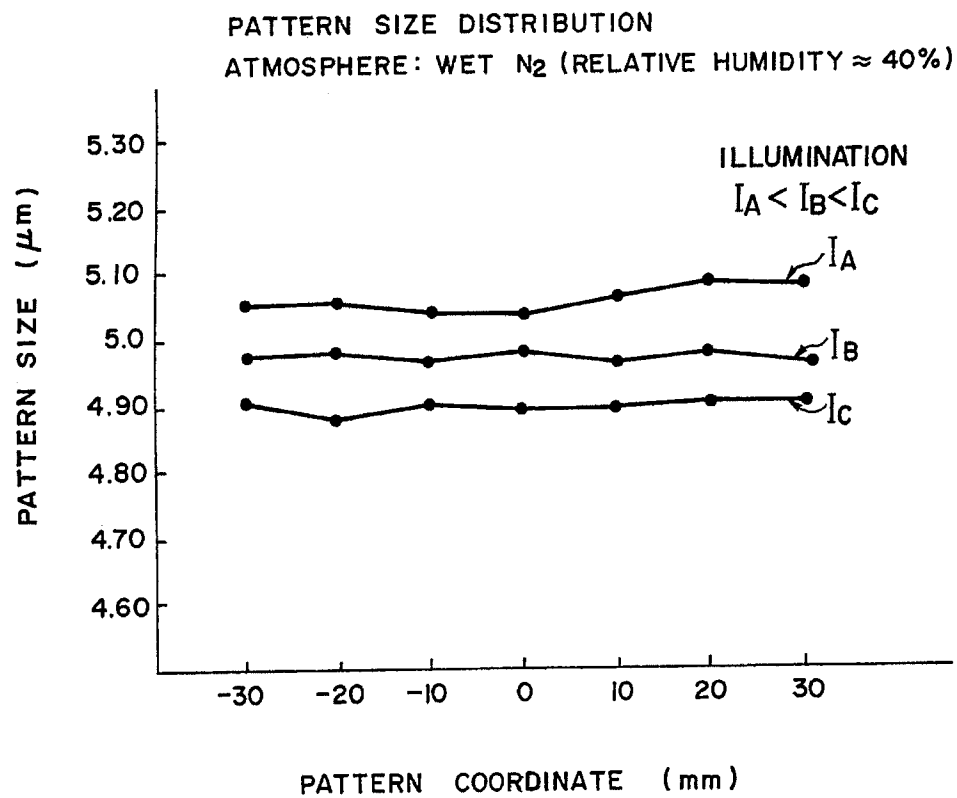


FIG. 5

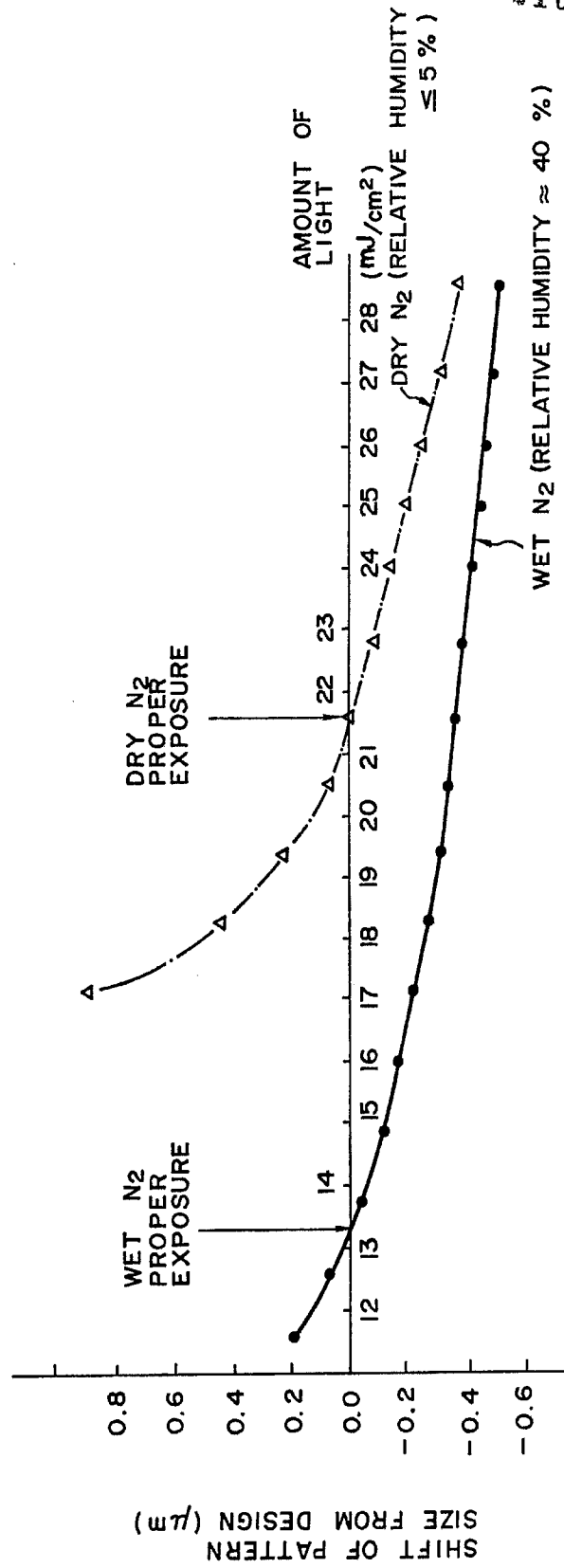


FIG. 6A

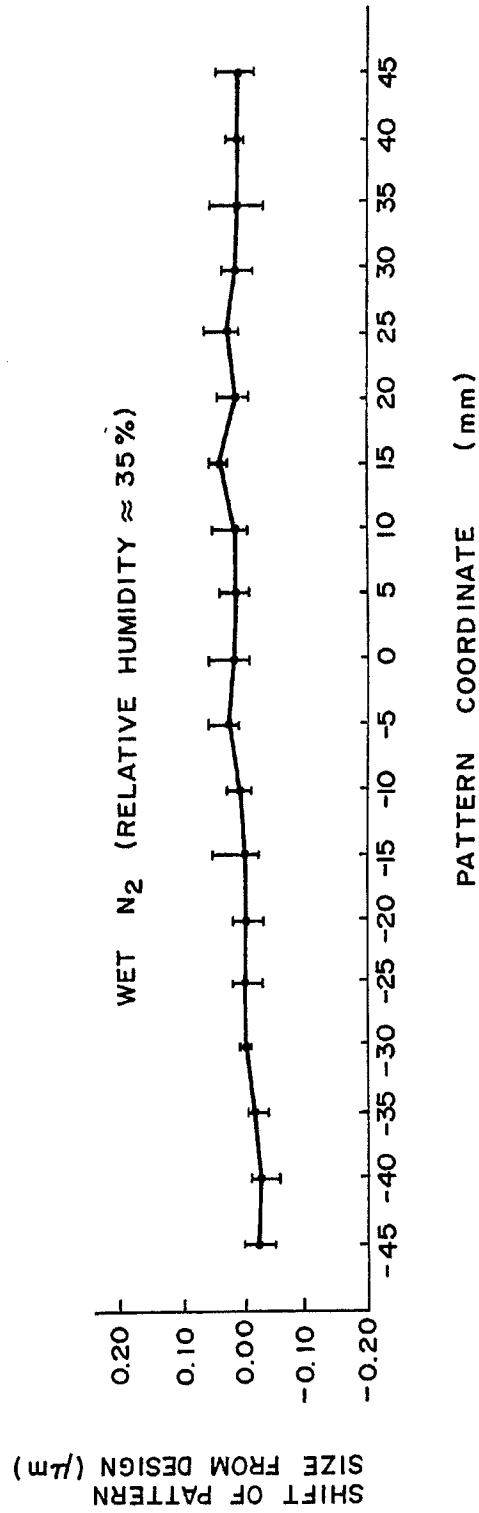
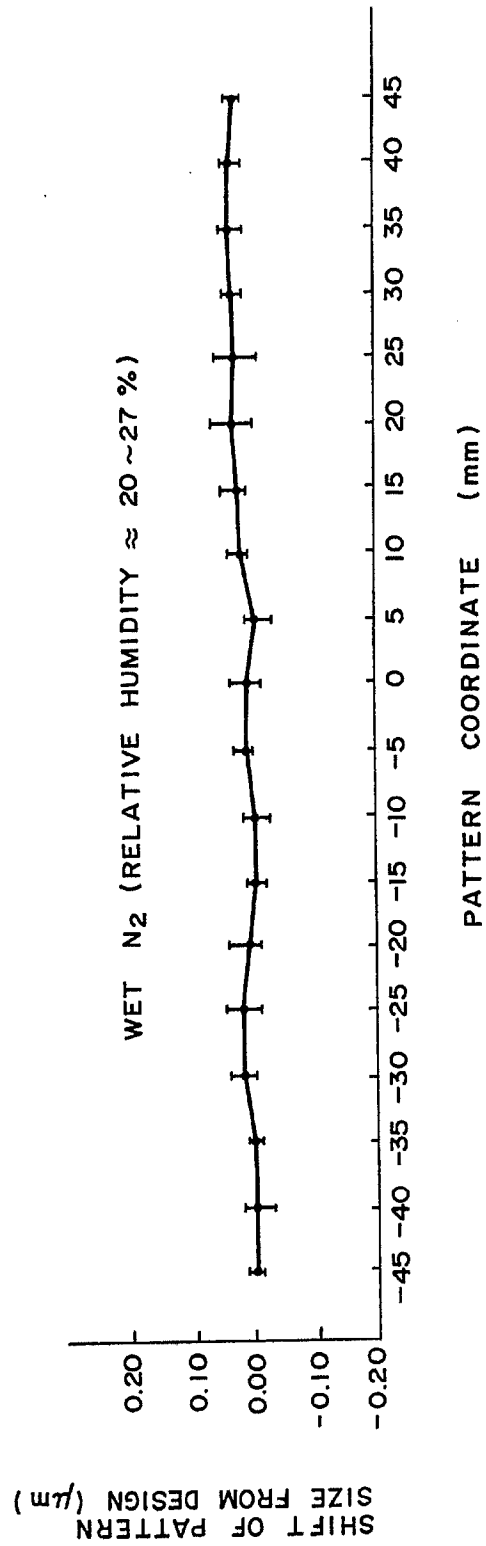


FIG. 6B



7/10

FIG. 6C

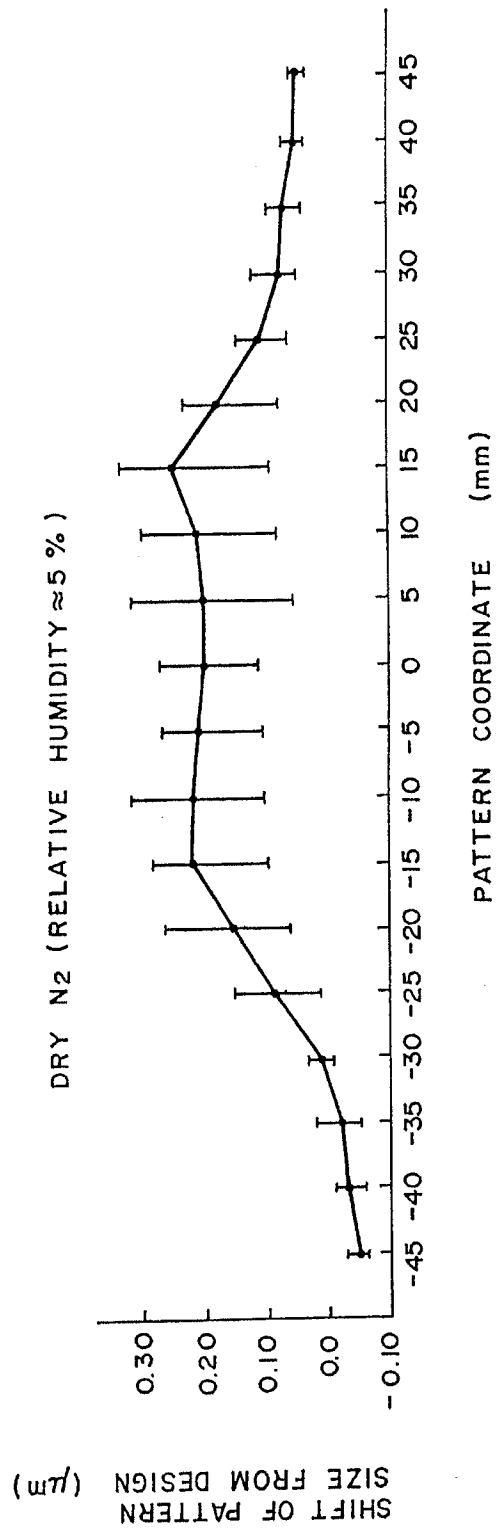


FIG. 7

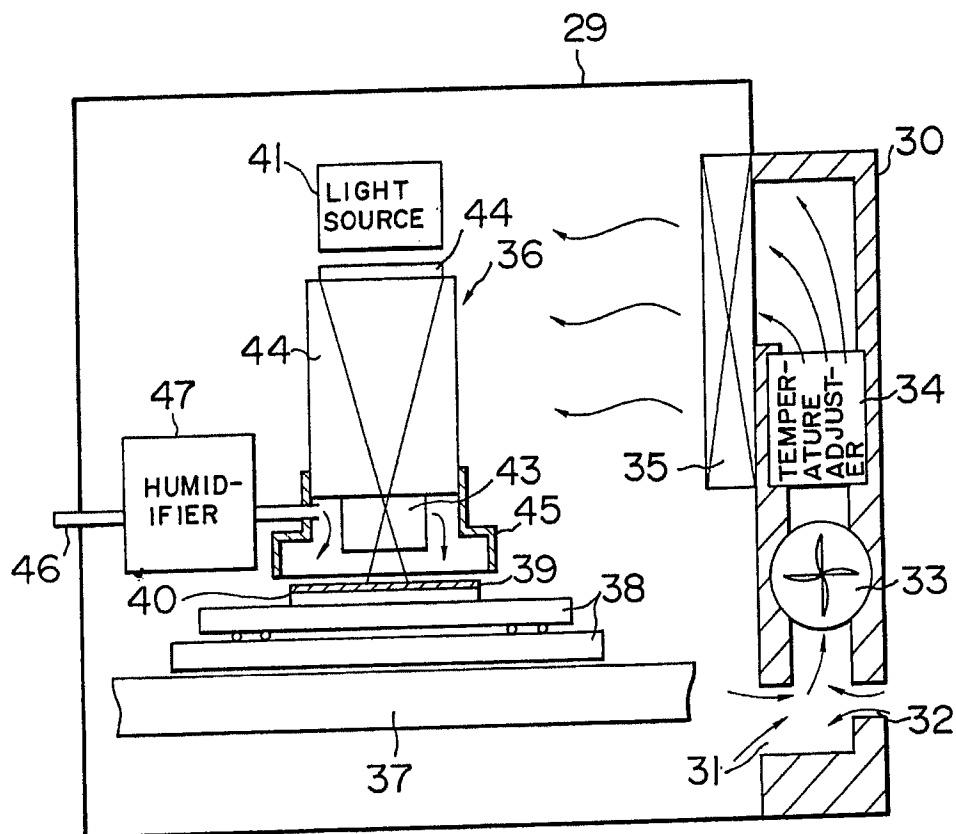


FIG. 8

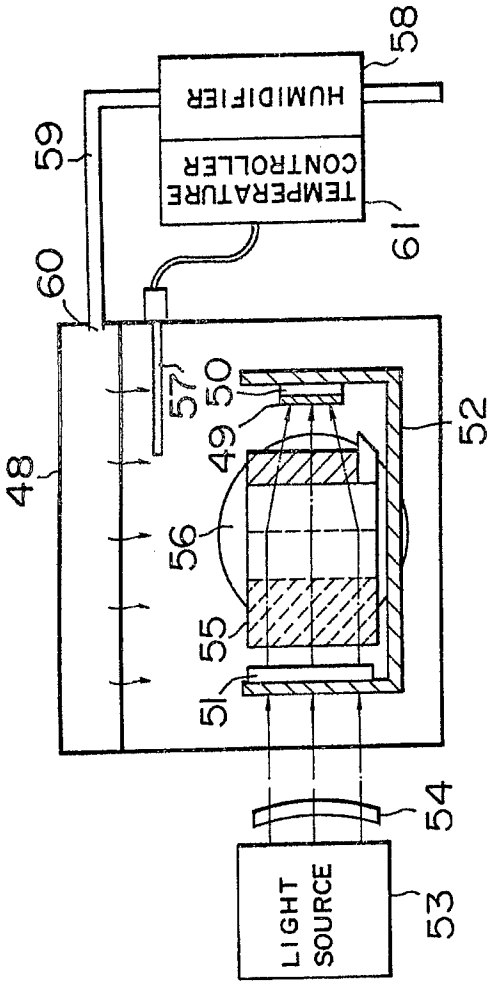
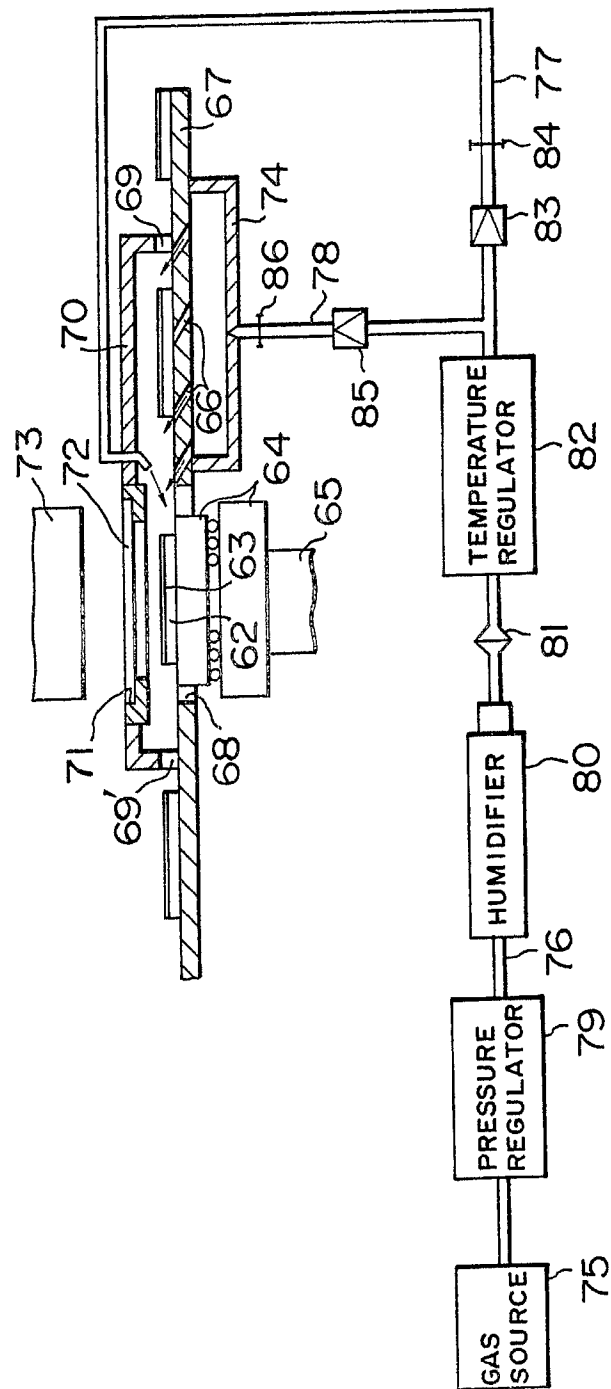


FIG. 9



SPECIFICATION

Exposure of uniform fine pattern on photoresist

5 This invention relates to a method and apparatus for optically copying an original pattern or picture onto a workpiece coated with photoresist and particularly to a method and apparatus capable of decreasing the local nonuniformity of the transferred
10 pattern.

In manufacturing semiconductor devices, it is often required to project a mask pattern onto a photoresist layer coated on a workpiece such as a wafer for forming a photoresist mask pattern on the
15 wafer surface. Similar projection process is required when making a so-called working photomask from a master reticle. The photoresist is known to exhibit a large difference in solubility between exposed and nonexposed portions by the photochemical effect of
20 radiation energy, in an inorganic or organic developer. Therefore, development will leave a negative or positive photoresist mask corresponding to the distribution of light energy on a workpiece such as a wafer. From this point of view, it can be
25 considered that uniform transfer of pattern free of local nonuniformity or unevenness can be obtained as long as the photoresist is exposed under uniform illumination.

However, when a photoresist mask is practically
30 formed on a workpiece using this kind of method, local nonuniformity in the pattern width or size in and among photoresist masks results.

Figure 1 shows an example of the distribution of a pattern width under three illumination conditions, $I_a < I_b < I_c$, in each of which a plurality of patterns are
35 projected successively onto a photoresist surface coated on a wafer by a step-and-repeat camera. Transferred pattern size clearly depends on the intensity of light as expected and seen from the figure. Further, there are variations in the pattern size
40 or width between the center and the periphery of each photoresist mask, although the successive patterns are exposed by the same amount of light energy.

The present inventors carried out experiments to investigate the reason of the latter nonuniformity. It has been found as a result of the experiments that the unevenness of the pattern size is particularly
45 noticeable in masks exposed in those exposing devices in which air is directly or indirectly applied to photoresist films, such as those using an air micrometer for adjusting focus and those using air for transferring workpieces. This may be ascribed to the following reasons.

In the photochemical conversion process of the photoresist, the water content in a photoresist, when the light energy acts upon the photoresist, is estimated to give a large influence on the pattern width, i.e., the photosensitivity of the photoresist. It is noted
55 that air conditioning is normally performed to regulate the humidity and the temperature of air in the exposing room during the exposure of the photoresist, for example in such ranges of $20 \pm 5\%$ and $18 \pm 3^\circ\text{C}$. These ranges of fluctuation, however, are con-
60 sidered relatively large for the exposure of photores-

ist. Further, the air for an air micrometer and for an air transferring device is usually supplied from a pressurized gas vessel and is allowed to impinge the photoresist surface and produce variations in water
70 content in the photoresist, which variations in turn produce nonuniform distribution of the photosensitivity over the photoresist surface. As a result, the pattern width becomes nonuniform for different locations. In the case of a step-and-repeat camera
75 equipped with an air micrometer as used in the experiment of Figure 1, the amount of air blowing onto the center of the workpiece is larger than that blowing onto the periphery during the process of exposure. For the positive type photoresist, this
80 causes a larger decrease in the water content in and hence a larger decrease in the photosensitivity of the photoresist at the central portion than at the periphery, which will result in the width of the photoresist pattern (unexposed portion) being greater at the central portion than at periphery. On the
85 other hand, when air is used in the air micrometer for the negative type photoresist, the negative type photoresist film is chemically reacted by the oxygen, etc. contained in the air and is subjected to a
90 decrease in the film thickness. Therefore, it is recommended that inert gases such as N_2 gas should be used in the air micrometer for the negative type photoresist to prevent chemical reaction in the photoresist film.

95 Therefore, an object of this invention is to provide a method of exposing a photoresist in which the photoresist is brought into contact with a gas set to a predetermined humidity separately from the ambient atmosphere to make the water content in the photoresist uniform at least over the surface
100 while being exposed. The original pattern is accurately projected and transferred to the photoresist coated on the surface of a workpiece due to regulated water content in the photoresist.

105 Another object of this invention is to provide an apparatus for exposing a photoresist comprising a humidity regulator in a gas supply section separate of a temperature and humidity control equipment for the ambient atmosphere so that the gas blowing to
110 the photoresist can be kept to a predetermined humidity.

The above and other objects, features and advantages of this invention will become more apparent in the following detailed description made in conjunction with the accompanying drawings, in which:

115 Figure 1 is a graph showing the distribution of pattern size obtained in a conventional device;

Figure 2 is a schematic diagram showing a reduction exposure device according to an embodiment of
120 this invention;

Figure 3 is an enlarged cross-sectional view of a humidifier used in the device of Fig. 2;

Figures 4, 5 and 6A to 6C are graphs showing the results of measurement of photosensitivity and pattern size showing the effects of an embodiment of
125 this invention; and

Figures 7 through 9 are schematic diagrammatic views showing constructions of other embodiments of this invention.

130 Figure 2 shows a projecting type reduction expos-

ure device, which is a preferred embodiment of this invention. The device, at least in the main part, is installed in an air-conditioned clean room. Description will be made first on the construction of this embodiment and then on its performance in conjunction with an embodiment of the exposing method of this invention. In this figure, reference numeral 1 denotes an XY table capable of moving along the horizontal direction and the direction perpendicular to the plane of the sheet in the drawing. On this table is mounted a workpiece (silicon wafer) 3 coated on its surface with a film of photoresist 2. Placed above the XY table 1 is a vertically movable barrel 4 which is provided with, at a lower portion, an objective lens 5 with an optic axis 0 and, at a top portion, a mask 6 having a mask pattern to be transferred onto the photoresist surface. The mask pattern on the mask 6 is reduced in size by the objective lens 5 and is projected and transferred onto the photoresist 2 in the step-and-repeat fashion by stepping action of the XY table 1. The objective 5 is contained in a casing 9 which is mounted on the barrel 4 and has an inlet opening 7 and an outlet opening (metering nozzle) 8. The inlet opening 7 is connected to a N₂ gas source 11 through a piping system 10 thereby to introduce N₂ gas into the casing 9, while the outlet opening 8 injects the gas onto the surface of the photoresist 2. The piping system 10 includes, from the upstream to the downstream, a first pressure reducer (valve) 12, a pre-filter 13, a first heat exchanger 14, a second pressure reducer 15, a humidifier 16, a fine filter 17, a second heat exchanger 18 and an air pressure type focusing device 19. The air pressure type focusing device 19 has a pressure difference detecting portion 20 which compares the N₂ gas pressure in the casing 9 with the reference gas pressure supplied from the second heat exchanger 18, and a focus control portion 21 which controls the vertical movement mechanism (not shown) of the barrel 4 according to the pressure difference detected. By comparing the pressures, the device detects the distance, e.g. of micron order, between the objective lens 5 and the photoresist 2 and, according to the pressure difference, controls the vertical position of the barrel 4 to adjust the focus of the lens. The humidifier 16, as shown in Figure 3, has a porous glass layer 24 permeable to liquid and gas, placed near the internal bottom of the container 23 which is plugged by a stopper 22. The humidifier 16 also has an inlet delivery pipe 25 passing through the porous glass layer 24 and an outlet pipe 26 connected to the upper space in the container 23. Deionized water 27 is contained in the container 23 to a level higher than the porous glass layer 24 but below the drawout pipe 26. The N₂ gas supplied through the delivery pipe 25 into the humidifier 16 bubbles up through the water 27 and porous glass layer 24 to the upper space in the container 23 from which it is sent into the drawout pipe 26. While the gas moves up through the water as bubbles, it is humidified. The moistened gas is removed of droplets when passing through the trap 28 formed bent immediately downstream of the drawout pipe 26 and then supplied to the fine filter 17. The deionized water is resupplied through the upper opening by removing

the stopper 22.

Now, description will be made on the exposing method using the exposing apparatus of the above construction.

The N₂ gas source 11 supplies N₂ gas of a relative humidity of 5% under the gage pressure of several atm. The gas is reduced in pressure by the first pressure reducer 12 to about 1.5 atm and is removed of dust or impurity particles by the pre-filter 13. The first heat exchanger 14 performs a preliminary adjustment on the gas temperature to set the N₂ gas temperature to, for example, 20°C, about 5°C lower than the temperature of the atmosphere in the space between the objective lens 5 and the photoresist 2. After this, the N₂ gas is further reduced in gage pressure to 1 atm by the second pressure reducer 15 and enters the humidifier 16 where it is humidified as described earlier. Setting the gas temperature and water temperature at appropriate values, the N₂ gas absorbs a desired amount of water vapor through the bubbling to have a predetermined humidity. The humidified gas, after being filtered by a fine filter 17, is sent to a second heat exchanger 18 where its temperature is made equal to the temperature in the space between the photoresist 2 and the objective lens 5 with an accuracy of $\pm 0.1^\circ\text{C}$ and is kept thereat. The humidifier 16 and the second heat exchanger 18 together perform the function of keeping the gas at the specified relative humidity. For instance, where the temperature is 23°C and the atmospheric pressure is 760 mmHg, the relative humidity to which the N₂ gas is kept is about 35%. It will be apparent that the humidifier 16 may precisely be temperature-controlled to enhance the control of humidity and temperature of the N₂ gas, but not necessarily. The N₂ gas thus humidified and temperature-adjusted, is then sent to the air pressure type focusing device 19 which acts at the average measuring gage pressure of 0.3 atm. From the focusing device 19, the gas is sent through the inlet port 7 of the casing 9 into the working space between the objective lens and the photoresist and surrounded by the casing 9. As a result, this space is filled with the gas of predetermined humidity, thereby keeping the water content in the photoresist constant.

Next, in this condition, the vertical position of the objective lens 5 is controlled by the air pressure type focusing device 19 based on the pressure difference between the pressure in the working space and the standard pressure supplied from the gas source (e.g. second heat exchanger), to project the mask pattern of the mask 6 onto the surface of photoresist 2. By operating the XY table 1 in appropriate way and projecting and transferring the mask pattern, a plurality of reduced mask patterns can be arranged orderly in lines on the photoresist surface.

As the result of the exposing process described above, the pattern formed on the workpiece after chemical treatment has almost constant width, as shown in Figure 4, regardless of whether it is located at the center or the periphery of the workpiece and unevenness in the pattern width is negligible. Comparison between the proper exposing condition, or the photosensitivity of photoresist, of the above method and that of the conventional method as

shown in Fig. 5 reveals that the photosensitivity obtained in this method is about two times greater than that of the conventional method.

- Nonuniformity of the pattern width has been checked by varying the humidity of N_2 gas. As can be seen in Figures 6A to 6C, for the relative humidity less than 5% the pattern size is not uniform; for the relative humidity more than 10% up to about 21 - 27% almost no irregularities are found; and for the relative humidity of about 35% the pattern size is found to be very stable. This result shows that it is important to keep the gas humidity at least at 10%. It should be noted here that the humidity mentioned above may vary to some extent as the N_2 gas temperature varies with variation of the ambient temperature of the exposing device. It should also be noted that for the different thickness of the photoresist (film thickness) conditions of the gas humidity and also the gas temperature may vary slightly.
- As to the exposing device, the humidifier 16 is not limited to the construction described above but various kinds of humidifier such as spray type, atomizing type, dew point type and vaporizing type can be used.
- Figure 7 shows another embodiment of a reduction exposing device installed in a temperature-regulated room and not equipped with an air micrometer. This device has an air conditioner 30 to keep the temperature in the temperature-regulated room 29 at a predetermined temperature by circulating air in the room 29. The air conditioner 30 consists of a return air inlet 31, an external fresh air inlet 32, a fan 33, a temperature adjuster 34, and an air filter 35. The exposing machine 36 comprises a base table 37, an XY table 38 mounted on the base table 37, and an optical system including a light source 41, a barrel 42 and an objective lens 43 and capable of projecting a mask pattern on the mask 44 onto the photoresist 39 coated on the surface of a workpiece 40 such as a silicon wafer mounted on the XY table 38. Mounted on the lower end of the barrel 42 is a casing 45 enclosing the objective lens 43 and the workpiece 40, to which a piping 46 leading to an air source (not shown) is connected through a humidifier 47.
- In the exposing device of this embodiment, the air which is controlled to a desired level of humidity by the humidifier 47 is blown from within the casing 45 to the entire surface of the photoresist 39 to keep the humidity of air near the photoresist surface at a specified value thus making the water content in the photoresist constant and uniform while the photoresist is being exposed. As in the preceding embodiment, this embodiment can also achieve uniformity in the pattern width. This embodiment is particularly effective for use in such devices as those which do not have air micrometers or in which the entire surface of photoresist is exposed at one time. Here, N_2 gas may be used instead of air for filling the space near the photoresist 39.
- Figure 8 shows an embodiment of a 1:1 (unit magnification) projection exposure device. The exposure device is partially contained in a temperature-controlled enclosure 48 which is disposed in a clean room, and comprises a holder 52, on the opposing sides of which are mounted a mask

51 and a workpiece 50 applied with a photoresist coating 49, and an optical system including a light source 53, a slit 54 formed of a thin glass prism serving for locally exposing the photoresist surface, an optical reflecting prism 55 and a reflecting mirror 56 and capable of projecting the mask pattern to the photoresist at a 1:1 scale. The temperature-controlled chamber 48 is provided with a temperature sensor 57 and an air inlet 60 connected with an air piping 59 in which a humidifier 58 is inserted. Based on the output from the temperature sensor 57, the temperature controller 61 provided to the humidifier 58 is controlled so as to regulate air to predetermined humidity and temperature are to supply the controlled air into the chamber 48. As a result, the air in the chamber and hence near the surface of the photoresist 49 is maintained at desired humidity and temperature and exposure is performed under these conditions.

- Figure 9 shows another embodiment of an exposing device of contact type or proximity type. A wafer 62 as a workpiece has a film of photoresist 63 coated on it and is placed on the XY θ table 64 that can be moved in the XY directions as well as the θ direction. The XY θ table 64 is vertically movable by a lifting device 65. At the same level as the XY θ table 64, is disposed a table 67 which has slant nozzles 66 and an opening 68 through which the wafer 62 on the XY θ table is exposed. A casing 70 mounted on the table 67 has openings 69 and 69' for feeding and retrieving wafers therethrough and an opening 71, opposite to the XY θ table 64, in which a mask 72 is disposed. An illumination device 73 is disposed above the mask 72 for exposing the mask pattern to the photoresist 63 on the wafer 62. The position of the wafer with respect to the mask 72 is adjusted by the XY θ table 64 and the lifting device 65. Below the table 67 is provided an air pressure type wafer transferring device 74. A gas source 75 of the gas supply section is connected to the casing 70 and to the wafer transferring device 74 through pipes 76, 77 and 78 for the supply of gas. The pipe 76 is provided with a pressure regulator 79, a humidifier 80, a fine filter 81 and a temperature regulator 82 from the upstream in this order; the branch pipe 77 is provided with a valve 83 and a pressure switch 84 and another branch pipe 78 with a valve 85 and a pressure switch 86.

The pressurized dry air (or any other gas required for the process) from the gas source 75 having a relative humidity of 10% or less and containing no dust is supplied to the humidifier 80 through the pipe 76. In this process the pressure regulator 79 regulates the gage air pressure to 1.5 atm. In the humidifier 80 the pressurized air is controlled to the specified humidity and temperature suitable to the exposure of the photoresist 63. The air is further removed of dust or impurities by the fine filter 81 and is regulated by the temperature regulator 82 to a temperature equal to that of the photoresist. The valve 85 installed in the branch pipe 78 is effective to adjust the amount of pressurized air to be fed to the transferring device 74 which transfers wafers one after another onto the XY table 64 by the pressurized air blowing out of the nozzles 66. The branch pipe 77

also sends the humidity- and temperature-controlled pressurized air to the casing 70 by way of the valve 83. In this case, the air blowing out of the end of the branch pipe 77 into the casing 70 may be made to eject like shower. In an example of operation, a silicon wafer disposed on the right end of the table 67 is mechanically pushed through the opening 69 to the gas pressure type transferring device 74, then transferred by air pressure and guided by a mechanical stopper on the XYθ table 64, and exposed thereat. After the exposure, the exposed wafer is mechanically pushed through the opening 69' to another side of the table. The gas blown from the gas pressure type transferring device 74 fills the space between the mask 72 and the wafer 62 and exhausted through the opening 68, 69', etc.

As a result, the air around the photoresist is kept to the specified humidity and temperature, making water content of the photoresist constant and uniform, so that the width of the pattern can be made uniform. Since the transfer action of the water transferring device 74 is performed intermittently, the air flow to the transferring device 74 is supplied by the air pressure switch 86 only when the wafer is moved onto the XYθ table.

This invention is not limited to the embodiments described above and modifications or alterations can be made without departing from the spirit of this invention. While the above embodiments mainly concerns the exposure of mask pattern on the photoresist coated on silicon wafers, this invention can also be applied to the formation of secondary masks from a primary mask.

As can be seen from the foregoing, the method and apparatus of this invention for exposing photoresist have the advantage that since the gas ejected onto a photoresist is set within a certain range of humidity, and preferably in a desired range of temperature, to keep the water content of the photoresist films uniform when forming mask pattern in photoresist films, the photosensitivity of the photoresist film can be kept uniform and therefore the pattern width can be made uniform regardless of the difference in the position of the photoresist surface even when there exists a slight variation in the photoresist film thickness and in the amount of gas ejected onto the photoresist surface.

CLAIMS

1. A method of exposing a photoresist coated on a workpiece comprising the steps of:

regulating the humidity of a gas contacting the photoresist, separately from the ambient atmosphere, to a value in a predetermined range such that water content in the photoresist is uniform at least over a predetermined area and at least in a period of exposure; and

radiating light onto the photoresist to expose the photoresist in said predetermined area under said regulated humidity.

2. A method according to claim 1, wherein the gas contacting the photoresist is regulated to a predetermined temperature range.

3. A method according to claim 1 or 2, wherein the relative humidity of the gas contacting the photoresist is 10% or more.

4. A method according to claim 1 substantially as hereinbefore described with reference to any one of Figures 2 to 5, 6A, 6B, 6C and 7 to 9 of the accompanying Drawings.

5. An apparatus for exposing a photoresist coated on a workpiece comprising:
an optical system having an objective lens for exposing the photoresist to form a pattern on it;
a gas supply section which supplies gas into the space between said objective lens and the photoresist; and

a humidity regulator connected to the gas supply section to regulate the humidity of the gas within a predetermined range.

6. An apparatus according to claim 5, wherein the gas supply section has a gas source; a gas blowing nozzle for blowing gas onto the photoresist and an air micrometer to adjust the focus of the optical system, and the humidity regulator is installed between the gas source and the gas blowing nozzle.

7. An apparatus according to claim 5, wherein the gas supply section has a casing at least partially enclosing the objective lens of the optical system and the workpiece, and the gas is ejected into the casing so that the gas comes into contact with the surface of the photoresist.

8. An apparatus according to claim 5, 6 or 7, wherein the humidity regulator has a container which contains water for humidifying gas and whose interior is formed as part of a passage through which the gas is allowed to pass.

9. An apparatus according to claim 5 substantially as hereinbefore described with reference to any one of Figures 2, 3 and 7 to 9 of the accompanying Drawings.

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